Information Continuity and Advanced Reasoning for Improved System Diagnostics and Prognostics

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Example High Cost of BIT False Alarms

- BIT false alarm $ costs in the F/A-18 program are very high
- False alarms also negatively impact fleet readiness and safety
- 75% of all cannot duplicate (CND) maintenance on the F/A-18 C airplanes was deemed the result of BIT false alarms

	Wasted Maintenance Man-hours	Wasted Maintenance Man-years	Unnecessary Aircraft Downtime (Hours)	Unnecessary Aircraft Downtime (Years)
O-Level CND	42,674	23.07	19,080	2.18
O-Level Removal with I-Level CND	15,482	8.37	6,801	0.78
I-Level CND	27,483	14.86	N/A	N/A
Total	85,639	46.30	25,881	2.96

- Table details F/A-18 A/B/C/D organizational and intermediate level wasted maintenance labor that resulted from BIT false alarms during 1999
- Based on these numbers, the annual wasted maintenance due to BIT false alarms causes a yearly loss of $1.7 million (F/A-18 alone!)
- Addressing these CND would save these $$'s and provide improvements in readiness, manpower, logistics, and safety

SOURCE: F/A-18 E/F Built-in-Test (BIT) Maturation Process; web: http://www.dtic.mil/ndia/systems

Information Continuity Motivation

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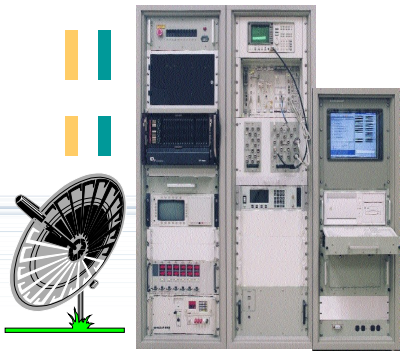
Embedded Diagnostics Improvements

- AI-based Diagnostics
- Model-based Fusion
- Analog Component Prognostics
- Onboard Ambiguity Group Analysis
- Information Capturing using Open System Architecture

At-Wing Diagnostics & Logistics Support

- Diagnostics Results & Ambiguity Analysis with Flight & Operational Conditions/Inputs
- Portable Maintenance Aids with OSA Communication



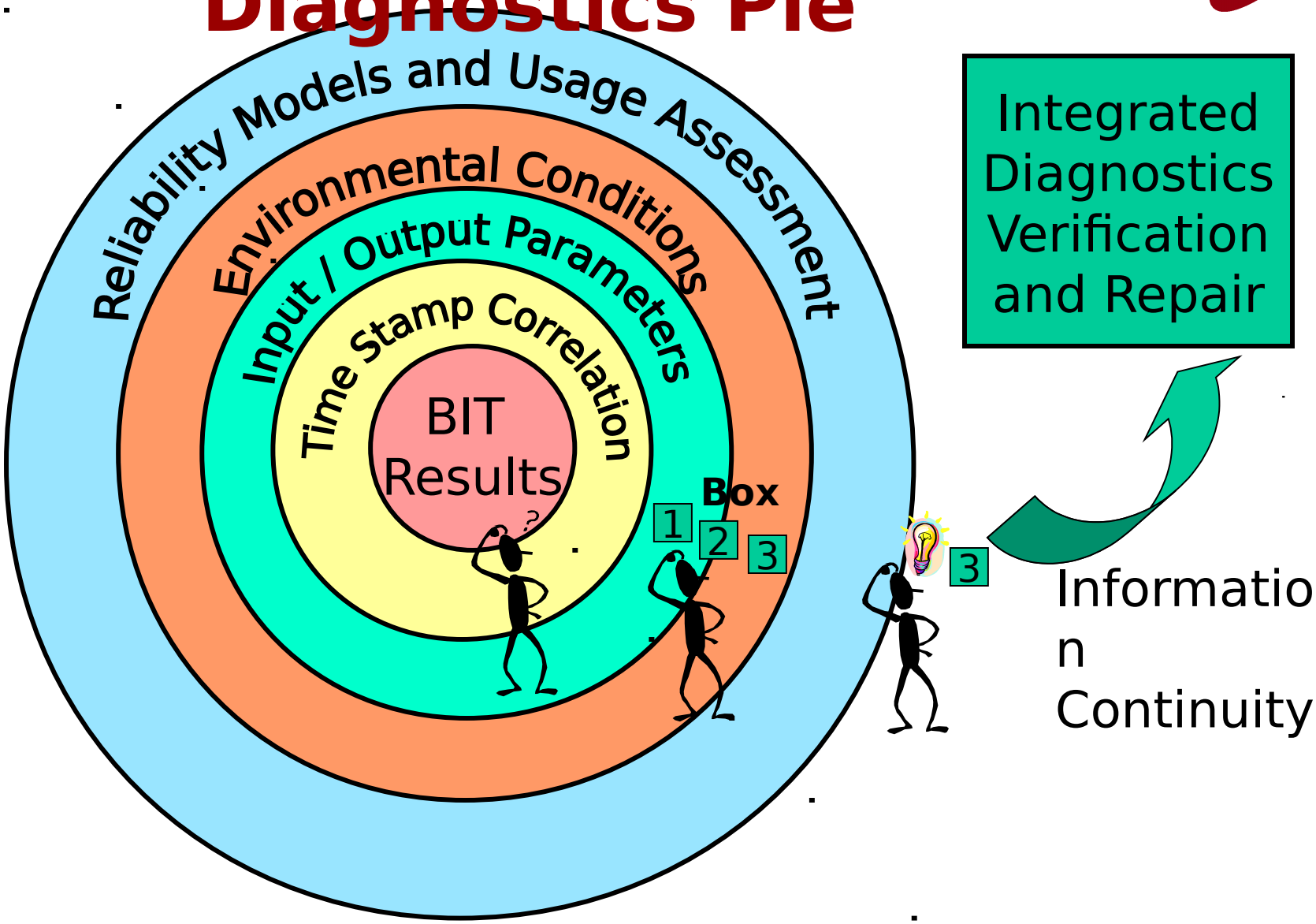
Information Continuity & Continuous Learning

- OSA Encapsulation of Diagnostic Results and Operational Conditions
- Ambiguity Analysis Results
- Links between Onboard, At-Wing & Depot Test Systems and Analysis

Avionics Diagnostics Database

- Case-Based Reasoning
- Data Mining
- Clustering
- Neural Tree

Growing the Embedded Diagnostics Pie

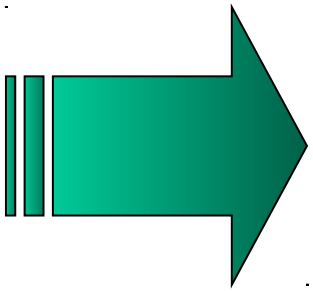


Systems Perspective and Evidence

- Legacy Federated → **System** composed of many LRUs from different manufacturers, independent BIT
- Future Integrated → **System** with specified interfaces and encapsulated interdependencies

Treated as a system, the individual components have relationships and dependencies that can be exploited to gain evidence.

- BIT
- Power Monitor
- Environmental
- Operational
- Historical Usage



Evidence

Example OSA XML Documents

```
<?xml version="1.0" encoding="UTF-8"?>
<!-- avionics data acquisition example by Patrick W. Kalgren (Impact Technologies) -->
<entryPoint xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
        xsi:noNamespaceSchemaLocation="http://www.osacbm.org/Models/ver_1.01/IDL/Schemas/DA_data_ver101.xsd">
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        <dataPage>http://www.impact-tek.com</dataPage>
        <outPortSet>
                <dataEventSet>
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                                <month>2</month>
                                <day>23</day>
                                <hour>19</hour>
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                                <second>55</second>
                                <millisec>0</millisec>
                        </time>
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                                </eventData>
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                                </outport.id>
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                                <transducer>
                                        <id>
                                                <idCode>1</idCode>
                                                <siteId>CF15-87</siteId>
                                        </id>
                                        <userTag/>
                                        <name>Power Supply Current </name>
                                        <outAmpl>14.38</outAmpl>
                                        <snip->
                                        ...
                                        <end snip->
                                        <dataEvent xsi:type="MeasEvent">
                                        <confid>100</confid>
                                        <eventData xsi:type="BinaryCode">
                                        <value>01101011</value>     // binary bus monitor BIT code
                                </eventData>
                                <outport.id>
                                        <idCode>AutoPilot</idCode> // LRU Identification
                                </outport.id>
                                <transdStatus>OK</transdStatus>
                                <transducer>
                                        <id>
                                                <idCode>3057</idCode> // LRU Sensor Identification
                                                <siteId>CF15-87</siteId> // Aircraft Identification (tail number)
                                        </id>
                                        <userTag/>
                                        <name>AutoPilot Self Test </name> // Autopilot BIT
                                </transducer>
                        </dataEvent>
                </dataEventSet>
        </outPortSet>
</entryPoint>
```
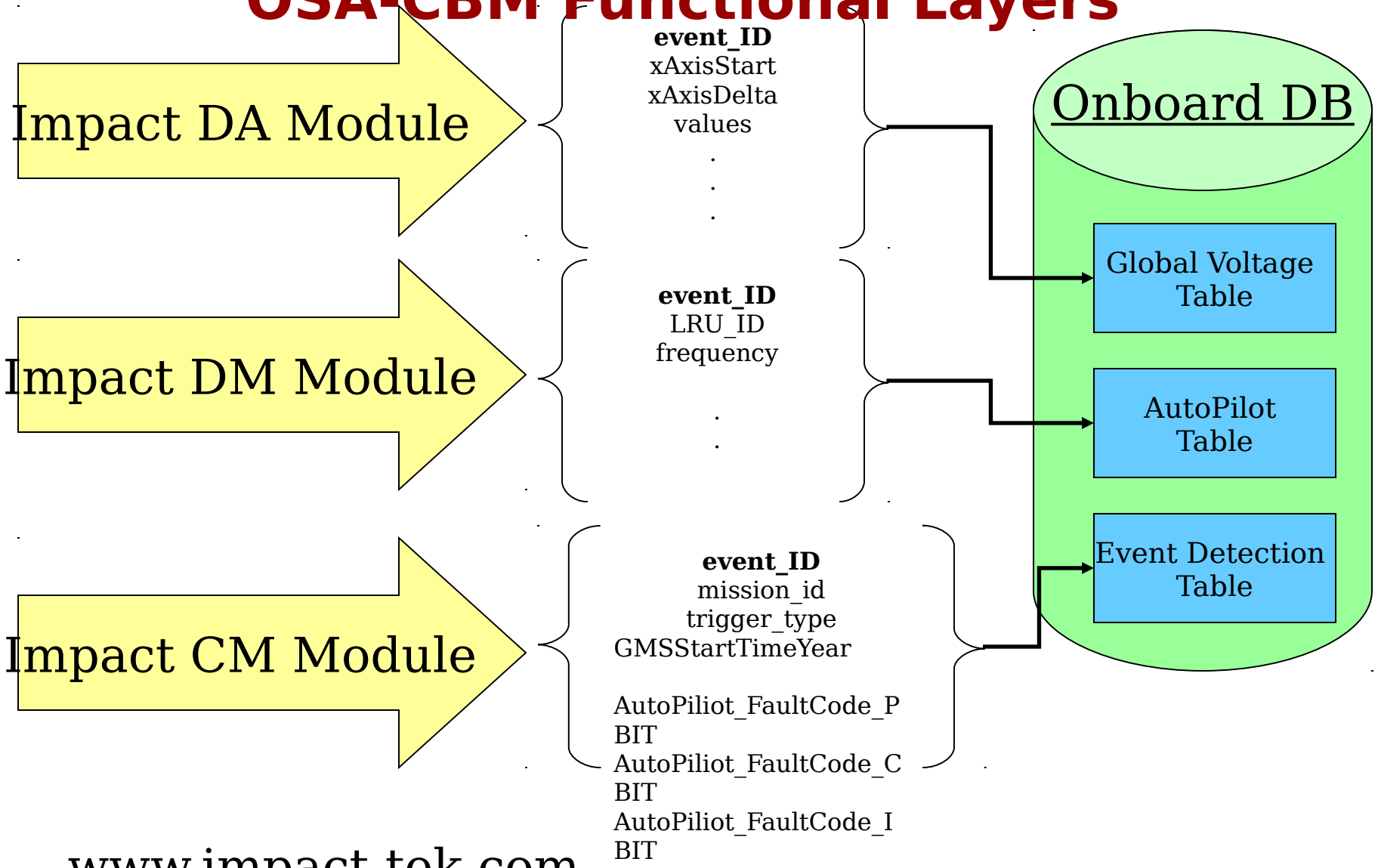
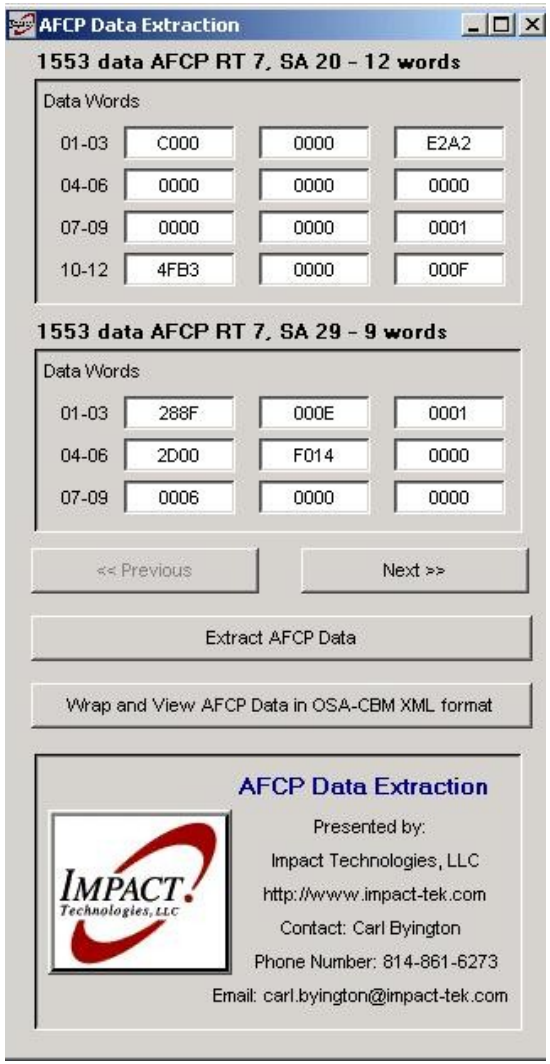

- XML Implementation with guidance from Open System Architecture for Condition-Based Maintenance schema
- Document structure specified by Schema at multiple Functional layers
  - Data Acquisition
  - Data Manipulation
  - Condition Monitor
  - Health Assessment
  - Prognostics
  - Decision Support
  - Presentation
- Documents are created and validated by schema on local or remote site (ATML)

XML Insertion into Database

OSA-CBM Functional Layers

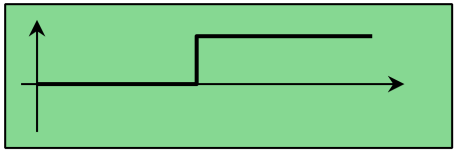
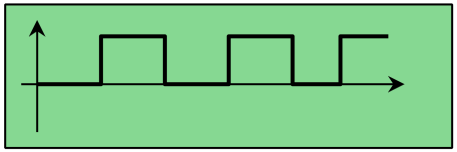
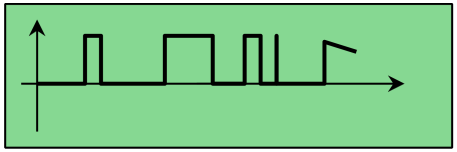
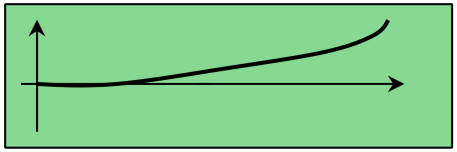


AFCP 1553 Interface and XML Conversion



- Interfaced with legacy hardware
  - Honeywell Aircraft Flight Control Processor
- Communicated through 1553 data bus
  - Laptop and Ballard Technology CM1553-3 PCMCIA Card
- Extracted raw, proprietary hexadecimal data from AFCP Remote Terminal memory
  - Created C executable using Ballard Technology Application Programmer's Interface
- Converted raw data to Meaningful Fault Codes
- Wrapped Fault Codes OSA-CBM XML

Problem Classification

Binary Fault		Simple fault/no fault. Can be detected by low level reasoners and BIT.
Intermittent but Repeatable		Intermittent fault occurs with high correlation to input parameter set (can be repeated). Can be isolated by a combination of low level reasoning and high level time and feature set correlation.
Intermittent but Pseudo-Random		Pseudo-Random intermittent faults are the most difficult to isolate. Require multiple levels of reasoning, adaptability of reasoners and continuous learning.
Graceful Degradation		Graceful component degradation can be detected and predicted using system models and time correlated tracking parameters. Refinements to predictions are made when usage profile diverts from norm or tracking parameters indicate.

Reasoning Techniques

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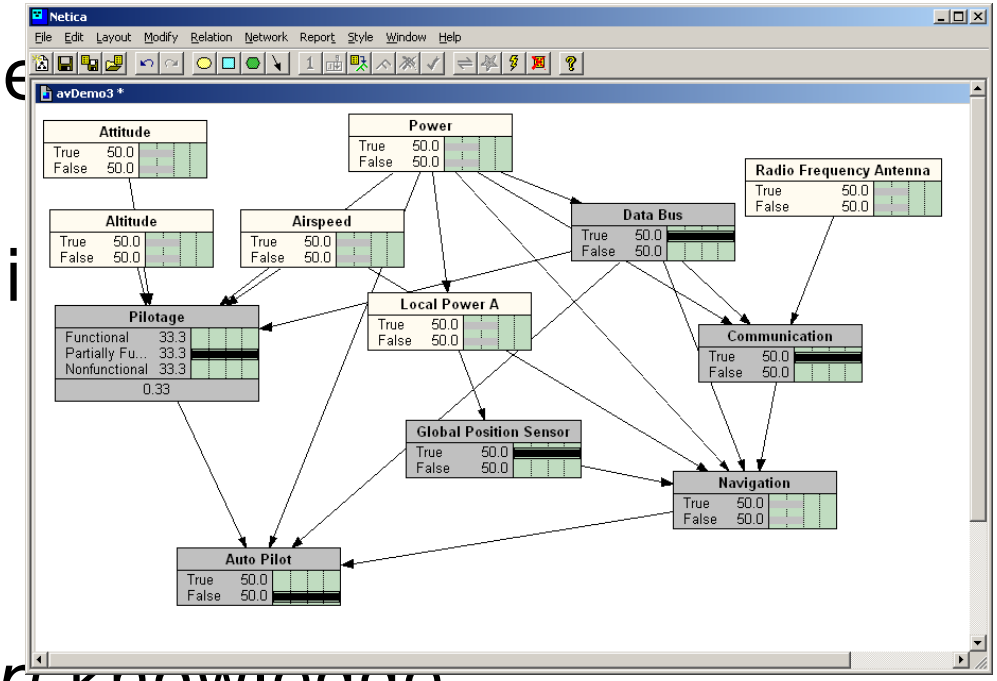
Technique	Typical Use	Distinguishing Characteristics	Applicable Data Sources	Limitations
Bayesian	Combination of results by different probabilistic indicators and classifiers.	An a priori knowledge of various involved probability distributions is required.	Output of detection and classification algorithms.	Computational complexity. A priori knowledge required. May not adequately represent uncertainty.
Dempster-Shafer	Combination of belief networks. Fuzzy systems use this method.	Generalization of Bayesian that allows for uncertainty (probability information that we don't have). Incorporates notions of "belief" and "plausibility".	Output of detection andclassification algorithms.	Output can be non-sensical, see classical two physician - three plausible diagnoses example.
Fuzzy Logic	Control systems and classification systems where the inputs and outputs can or should be described in plain language.	Can provide estimation without detailed knowledge. Easy to develop and understand (plain language). Utilizes the concept of partial truth.	Any data that can be organized into sets. Set relationship described with a membership function.	Output is imprecise. Functional output creates discontinuous functions giving random noise.
Neural Net	Classification in complex, typically non-deterministic systems.	Structure created via supervised learning. Can account for poorly understood system aspects. Can adapt to account for new knowledge.	Observed parametric data. Can be useful with noisy data ar data with gaps.	Difficult to understand. Requires considerable training data.
Genetic Algorithms	Systems that require evolution. Can be used where little is understood regarding the physical and logical processes of the system. Optimization and error minimization.	Can be utilized in an immature form and expected to evolve in time to an optimal solution.	Observed parametric data.	Evolution can be slow to develop and can oscillate dramatically while hunting for a solution.
Case-Based Reasoning	Useful in systems that are not easily described mathematically.	Requires comprehensive system experience. Assumes prior correct decisions will apply to new situations. Difficult to evolve.	Database of previous problem cases and solutions. Textual description of problem.	Solutions provided are typically sub-optimal unless a large historical database exists. Difficult to manage change.
Fault Tree Analysis	System diagnosis/troubleshooting.	Requires complete expert definition of failure modes for system under test.	Fully developed FMECA where all failure modes are defined.	Rigid construction suffers from brittleness. Unable to evolve.
Model Based Diagnostics	Mechanical systems with well understood physical properties.	Requires comprehensive knowledge of system component reliability.	Known physical attributes of a system.	Considerable requirement for *a priori* system knowledge. Often costly to implement.
Kalman Filter	Control systems, optimal combination of inputs	Recursive nature maintains prior knowledge of system without the processing overhead of maintaining all prior data. Low computational complexity. Can adapt to changing observational conditions.	Observed parametric data.	Limited applications.
Markov Model	Modeling component systems reliability(eg. electronic equipment).	System evolution is independent of current state.	State description of system. Can output MTTF & MTBF.	Interative process can be resource intensive.
Statistical Trend Analysis	Event detection.	Pure statistical method. Assumes independence and normal distributions of data under normal operating conditions.	Numerical features extracted from raw data. Mostly useful for anomaly detection.	Trend path of feature may not be monotonic. Considerable historical data requirement.

Bayesian Network

- ***High Level*** Reasone
- Describe Entities
- Describe Relationshi
  - Process
  - Physical
  - Proximal
- Encapsulates *a priori* knowledge
- Permits robust diagnostics with incomplete knowledge or modeling capability



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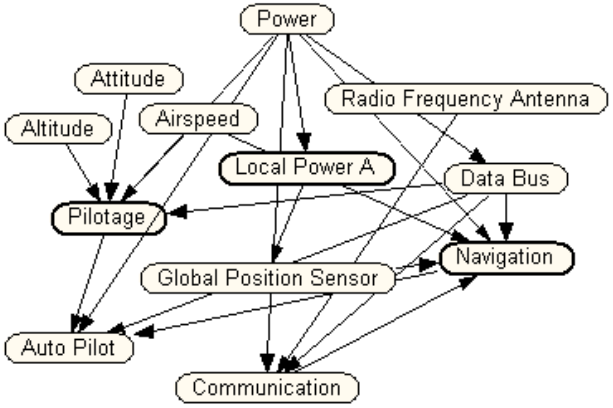
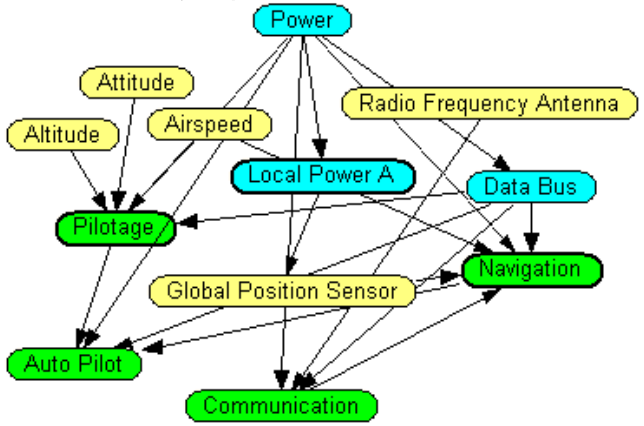
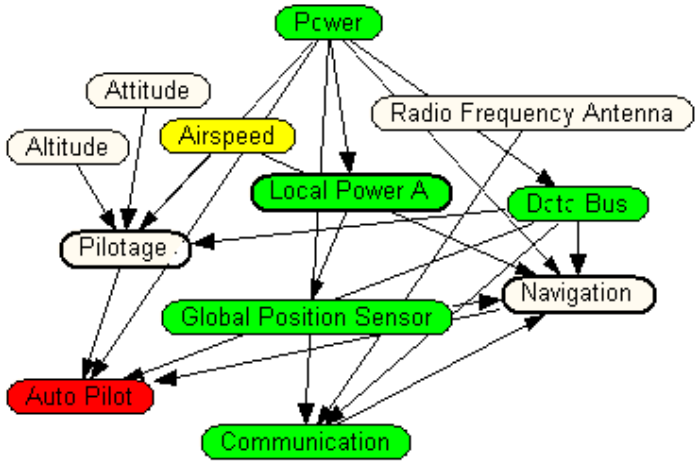
Top Level Reasoning

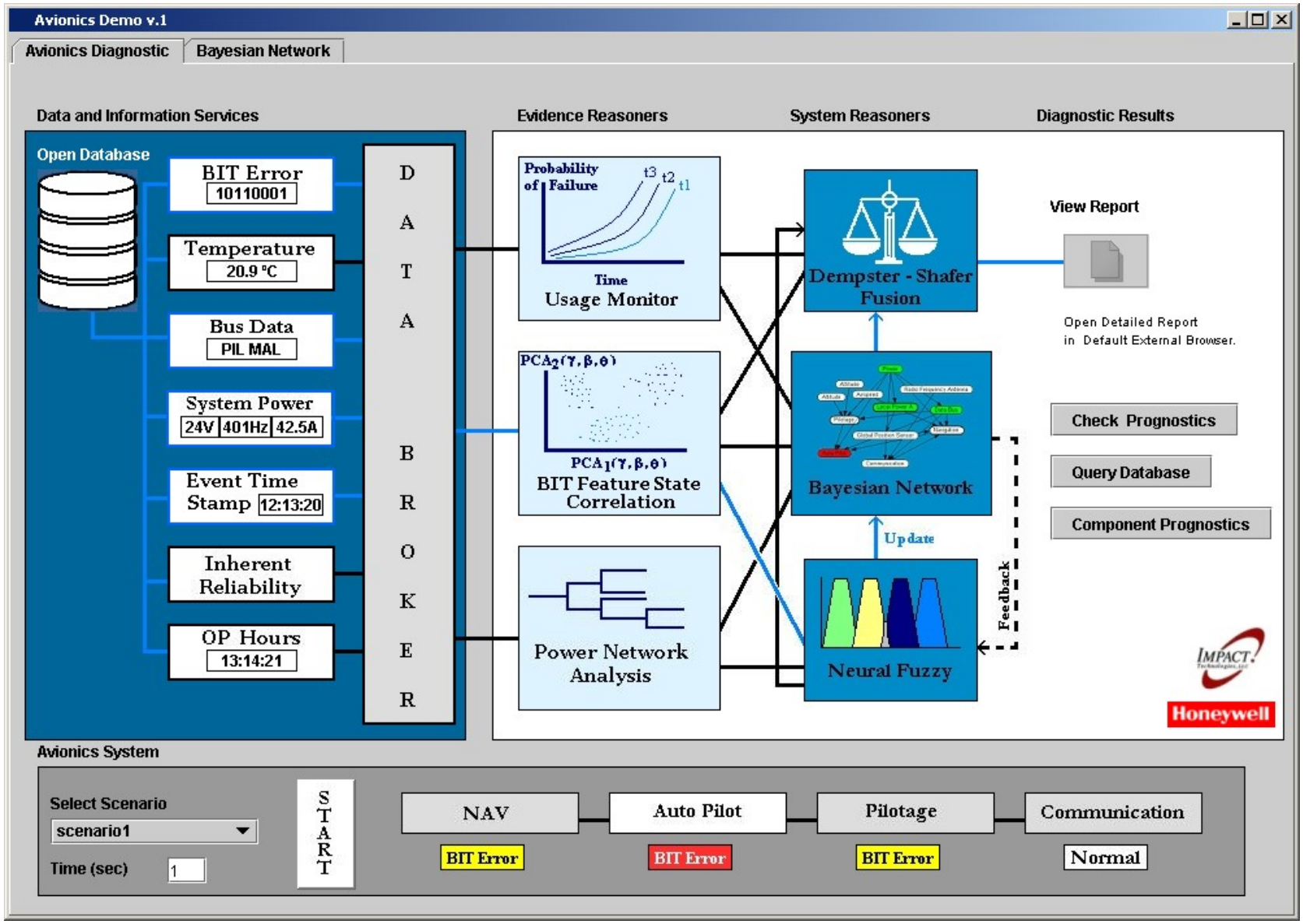


1. Initial State *a priori* relationships
2. BIT & Sensor Knowledge
3. Failure and Inference





Evidence Fusion and Bayesian N



At-Wing Evidence Analysis and Fusion Techniques

- Data or Knowledge fusion - the process of using collaborative or competitive information to arrive at a more confident decision both in diagnostics and prognostics
  - Should play a key role in terms of producing useful features, combining features, and incorporating new evidence
- Several different architectures and implementation choices for fusion
  - Bayesian and Dempster-Shafer Combination, Voting, and Fuzzy Logic Inference

Ex. Bayesian Fusion

$$P(f_1|O_n) = \frac{P(O_n|f_1)\,P(f_1)}{\sum_{j=1}^{n} P(O_n|f_1)\,P(f_1)}$$

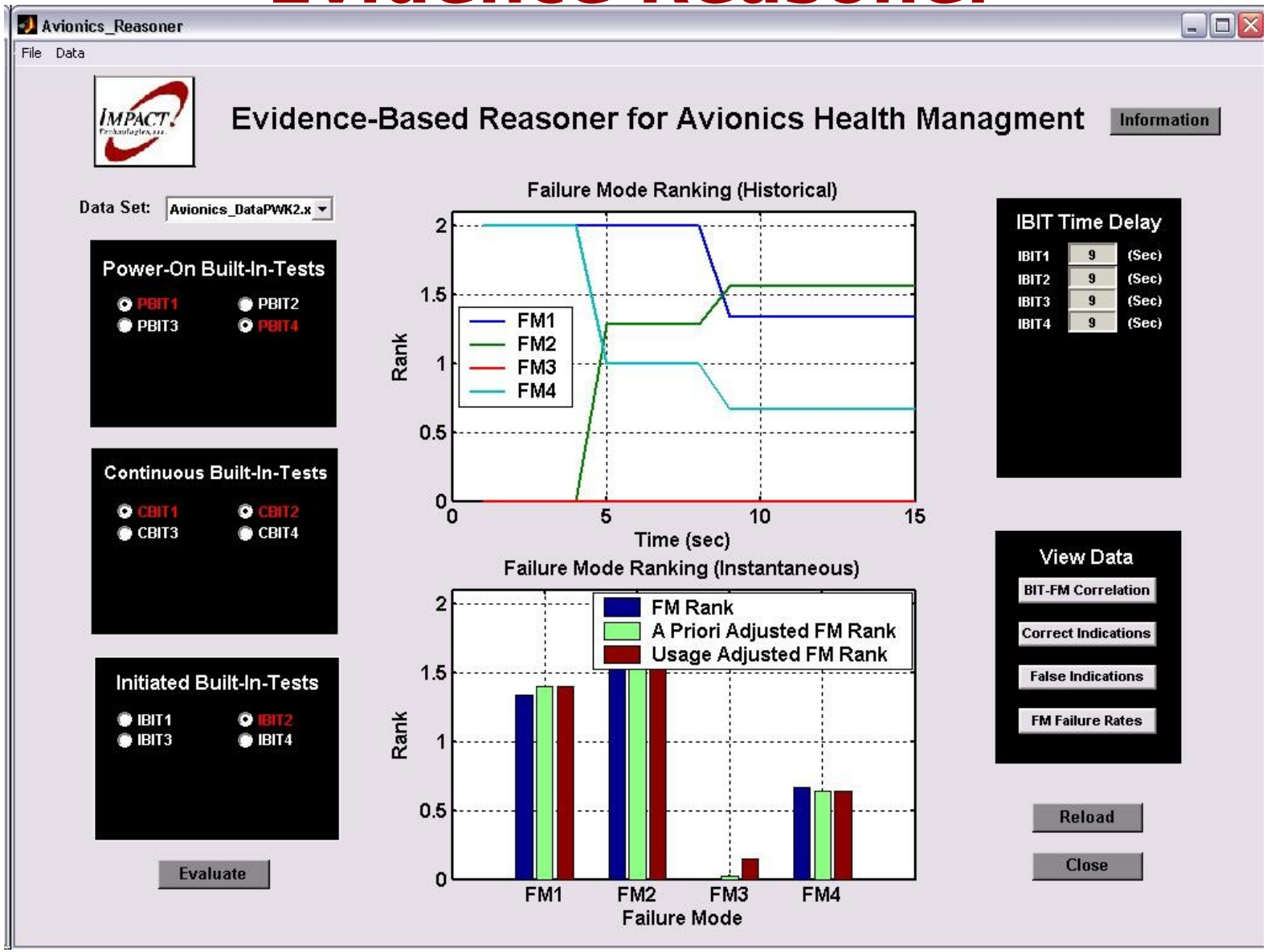
Where:

$P(f_1|O_n)$ = probability of fault (f) given a diagnostic output (O)

$P(O_n|f_1)$ = probability that a diagnostic output (O) is associated with a fault (f)

$P(f_1)$ = probability of the fault (f) occurring.

Positive + Negative Evidence Reasoner



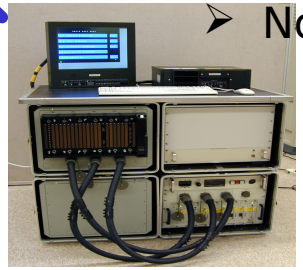
Integrated Diagnostics Results

- Prioritized list of actions to be performed by maintainer
- Rankings by confidence
- Rankings by greatest benefit for ambiguity reduction
- Opportunity for maintainer feedback to reconfigurable TPS
- Executed repair history
- Linked to Maintenance Action Form

Potential Technology Transition

- Integration of multiple OSA Health Indications
- Bus Monitoring and Data Fusion
- Neural Network and low level reasoners
- Wrapping proprietary data streams in OSA
- Storing and Brokering in OSA database
- System Level Diagnostics
- Prognostics and Prediction
- On-board and At-wing Reasoning
  - Bayesian Belief Network
  - Case-based Reasoning
  - Novel Evidence-based BIT

Metadata and ATML

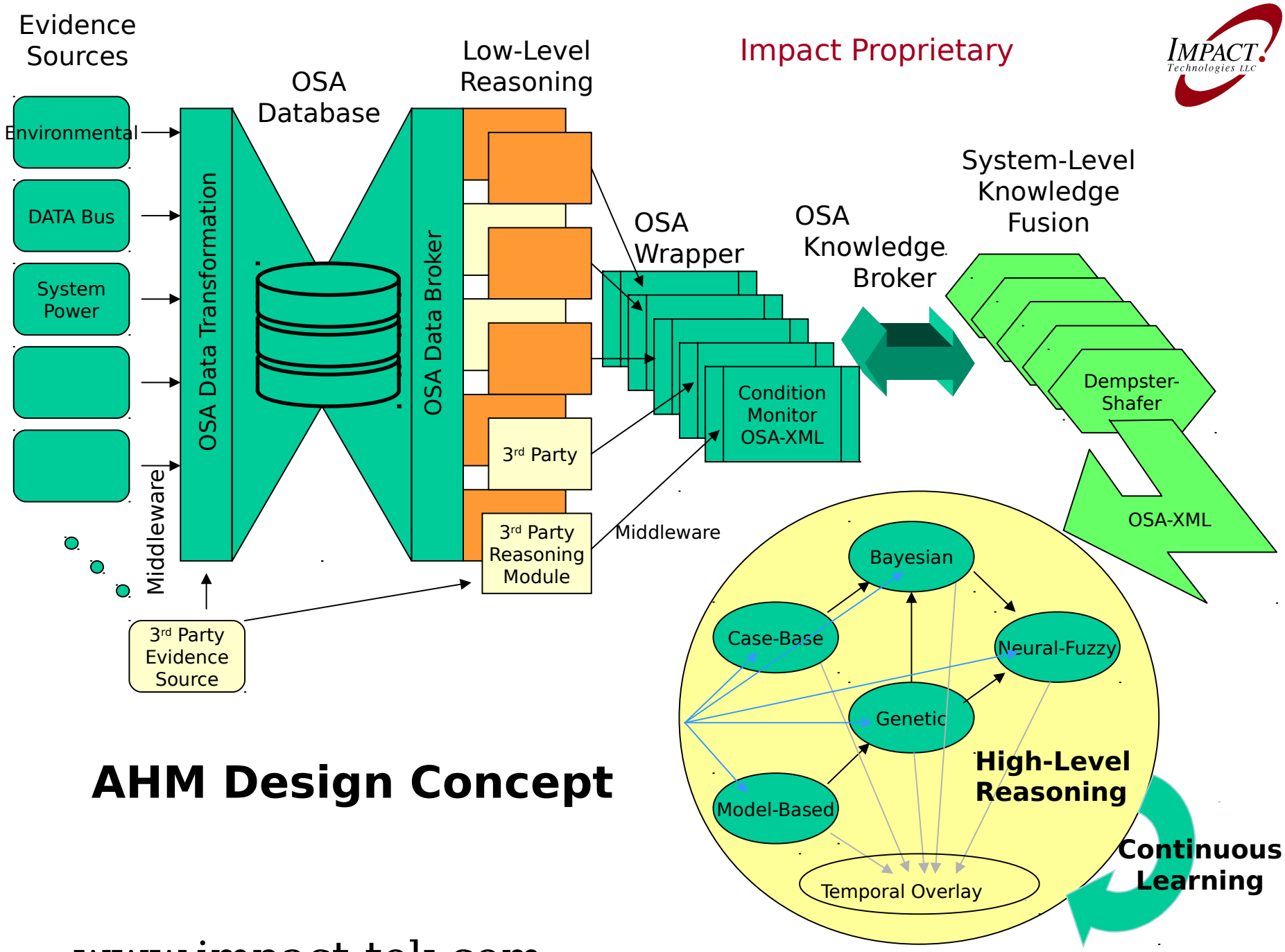


ARGCS and At-Wing Verification and Link to Logistics

Backup Slides

Summary of Progress

- Demonstrated Multiple Component Avionics Health Management with Bayesian Belief Network
- Demonstrated OSA Data Representation and Transport
  - Automated 1553 Data Interface and Code Extraction
  - Proprietary Fault Code to XML
  - XML to Database
  - Database to Reasoners
- Developed Innovative BIT Reasoner for Ambiguity Reduction
- Proposed Architecture to Support Information Continuity
- Coordinated Prototype Development with Honeywell



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AHM Design Concept

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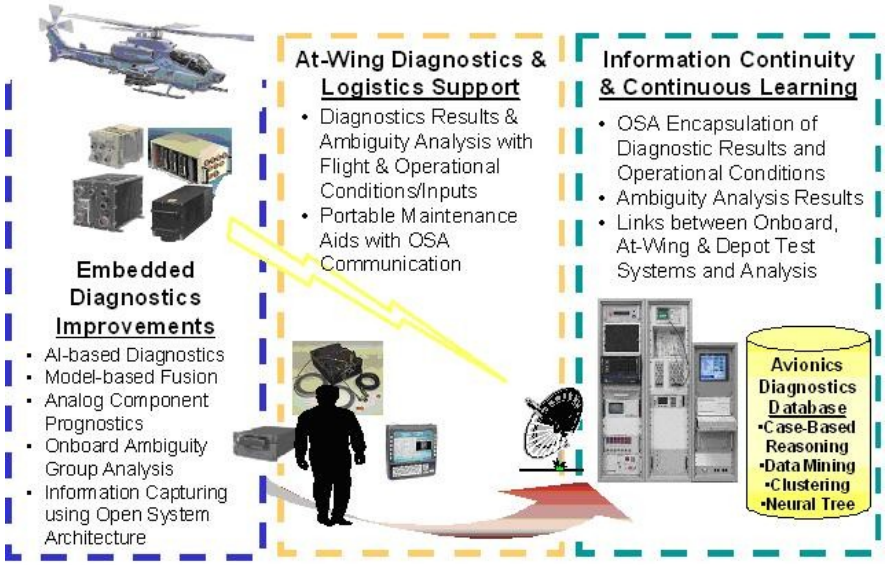
H-1 Upgrade Program

- H-1 Program to remanufacture/upgrade U.S. Marine Corps fleet of AH-1W Super Cobra attack helicopters and UH-1N Huey combat utility helicopters
- Strong emphasis on commonality between the vehicles in order to reduce logistics support costs – onboard and offboard
- Current plan for integrated avionics suite upgrades
- 180 Super Cobras will be upgraded to AH-1Z
- 100 UH-1N helicopters upgraded to UH-1Y
- Low-rate initial production (LRIP) to begin in 2004 and initial operating capability in 2007.
- Bell Helicopter Textron forecasts increasing demand for the AH-1Z, as other nations, such as Turkey and Israel, are considering upgrading their fleet of AH-1's.

http://www.awgnet.com/shownews/01paris4/intell04.htm
http://www.flug-revue.rotor.com/frtypen/FRErstfl/FR01Erst/PRUH-1Y.htm
http://www.chinfo.navy.mil/navpalib/policy/vision/vis02/vpp02-ch3c.html
http://www.aviationnow.com/avnow/news/2001/uh1yff.htm

Intelligent Embedded Diagnostics and Open Architecture for Avionics Health Management (AHM)- SBIR Phase II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• Portable Maintenance Aids with OSA Communication
Information Continuity & Continuous Learning
• OSA Encapsulation of Diagnostic Results and Operational Conditions
• Ambiguity Analysis Results
• Links between Onboard, At-Wing & Depot Test Systems and Analysis
Avionics Diagnostics Database
•Case-Based Reasoning
•Data Mining
•Clustering
•Neural Tree

Operational Concept

DESCRIPTION / OBJECTIVES / METHODS

- Capable of avionics subsystem and component identification, performance monitoring, prognostic prediction, and severity classification.
- Implement specific evidence-based and neural network reasoners for on-board or at-wing diagnostic assessment.
- Demonstrate applicability, adaptability in open architecture, and effectiveness of the advanced diagnostic/prognostic reasoners applied to legacy avionics systems. Reduce 'I' level turnaround time and repair costs.

MILITARY IMPACT / SPONSORSHIP

- AHM technology development targeted for upgradeable and future weapons systems
  - UH-1Y & AH-1Z at-wing and test equipment
  - F/A-18 Smart TPS Analysis modules
- Honeywell D&SS is partner on project and working towards additional transition:
  - RAH-66 Commanche and C130/141

BUDGET & SCHEDULE

TASK	FY03	FY04	FY05
Design & Develop AHM Architecture			
Develop AHM Software Modules			
Customize & Apply to application arenas			

Budget: 0.75M through 3Q05 (initiated 3Q03)

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